Advances in Production Engineering & Management
Volume 10 | Number 2 | June 2015 | pp 73–86
http://dx.doi.org/10.14743/apem2015.2.193
ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

Predictive analysis of criterial yield during travelling wire electrochemical discharge machining of Hylam based composites

Mitra, N.S.[a,*], **Doloi, B.**[b], **Bhattacharyya, B.**[b]

[a]Production Engineering Department, Haldia Institute of Technology, Haldia, India
[b]Production Engineering Department, Jadavpur University, Kolkata, India

A B S T R A C T

Travelling wire electrochemical discharge machining (TW-ECDM) has great potential for machining advanced non-conducting materials such as zirconia, alumina, silicon nitride, diamond glass, rubies and composites such as FRP etc. Composite materials possess higher strength, stiffness, and fatigue limits which enable structural design more flexible than with conventional metals. Over recent years precision machining of composite materials has gained in importance. The presented research paper includes a description of an indigenously developed TW-ECDM set-up for performing experiments on composite materials such as fibre reinforced plastic. This paper also presents analyses of machining parameters such as material removal rate and radial overcut for different input parameters such as pulse on time, frequency of power supply, applied voltage, concentration of electrolyte and wire feed rate. Taguchi method-based optimization analysis was also done for achieving minimum radial overcut and maximum material removal rate during the cuttings of grooves on Hylam based fibre reinforced composites. Multiple regression models were also established for both material removal rate and radial overcut by considering the more important process parameters for cutting grooves on Hylam based fibre reinforced composites. Finally, a back propagation neural network was applied for predicting the responses and those predictions are compared with the experimental results.

A R T I C L E I N F O

Keywords:
TW-ECDM
Groove cutting
Fibre reinforced composites
Taguchi method
Artificial neural nets

**Corresponding author:*
nsmitra@rediffmail.com
(Mitra, N.S.)

Article history:
Received 2 March 2014
Revised 24 March 2015
Accepted 26 March 2015

1. Introduction

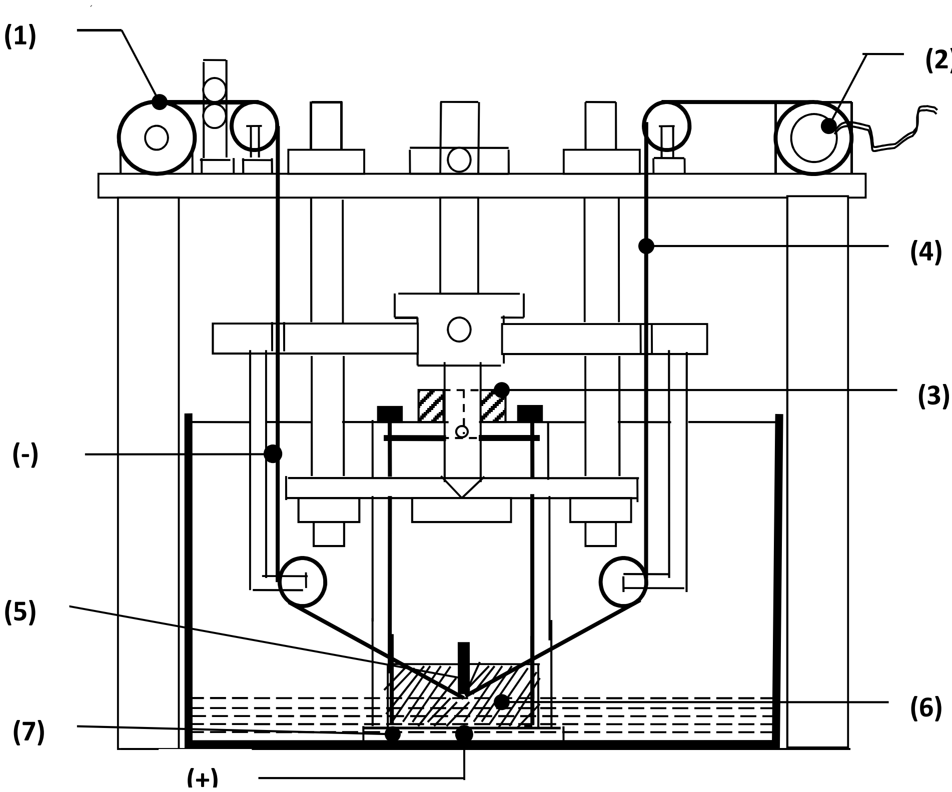
The researchers are urgently looking for techniques to keep up with the development of new materials such as engineering ceramics and composites etc. [1]. The demand for machining hard and brittle materials is steadily increasing in many applications. Presently various non-traditional machining processes are available but the inherent problems associated with these processes are thermal damage due to large heat affected zone, high tool wear rate, low material removal rate, high surface roughness, poor dimensional accuracy etc. Precision machining of fibre reinforced plastic (FRP) is also a challenge. Hylam is a mixture of cellulose, adhesive based on modified epoxy resin and hardener, the tensile strength and Young's modulus of which vary with fibre content. It has important properties like electrical insulation, moisture resistance and corrosion resistance. Fibre reinforced composites are widely accepted in structural and non-structural applications like household goods, switchboards and control panels. With conventional machining the laminated structure of FRP is damaged and machined surface becomes rough. To cope up with these challenges, manufacturing scientists are making use of the combined hybrid machining process, which also reduces some adverse effects of individual process. Electrochemical arc machining (ECAM) is found to have scope for electrically conductive materials. Electrochemical discharge machining (ECDM) [2-4] can be used for electrically conducting engineering materials. Further the traditional method of slicing ceramics depends upon the grinding force of hard particles and grinding results in micro-cracks. For slicing electrically non-conducting materials, Traveling wire electrochemical discharge machining (TW-ECDM) is a viable option [5, 6]. TW-ECDM is a complex combination of ECM and wire-EDM. In TW-ECDM, a pulsed DC power is supplied between the wire and auxiliary electrode. In this process, the conducting wire is used as cathode and auxiliary electrode is used as anode. In this process, the conducting wire is always in contact with the non-conducting workpiece material. As the pulsed DC power is supplied, hydrogen and vapour bubbles are formed and accumulated near the wire surface. With the further increase of applied voltage, the electric spark discharge occurs between the wire and the electrolyte across the insulating layers of gas bubbles. As the job surface is kept in the sparking zone, material is removed mainly due to melting and vaporization of the workpiece material. The feasibility study of machining FRP with ECSM was made [7]. Machining of non-conducting materials such as alumina, glass is still a major problem and although ECSM is most popular machining technique for those material it has certain difficulties. If ordinary cutting tools are used, the results are not so good like electrochemical spark abrasive drilling of alumina and glass [8]. An attempt was made to measure the true time varying current of ECSM to reveal the basic mechanism, temperature rise and material removal [9]. Spark assisted chemical engraving (SACE) had been investigated using current/voltage measurement and photographs [10]. A preliminary study of a pulse discriminating system was carried out for developing a control strategy of ECDM [11]. A thermal model was developed for the calculation of the material removal rate during ECSM [12]. Micromachining of non-conductive ceramics and composites has been attempted by ECSM and TW-ECSM [13-18]. Parametric analysis of TW-ECDM process using developed setup has also been attempted [19].

From the above past research activities it is understood that focus was mainly on the TW-ECDM or ECDM process and developing a model based on statistical experimental design. But no attempt was made to determine the dominant and recessive parameters of the process and there was no attempt to reduce the cost while increasing the quality. Also there were very few efforts in predicting the output from a set of input variables. Further FRP is a new material which is extremely important for application.

Keeping the above past research activities in view, this research paper includes Taguchi method based parametric analysis on TW-ECDM cutting of groove on flat surfaces of Hylam-based fibre reinforced composite workpiece. Multiple nonlinear regression analysis has also been done to find out the empirical relationship between the responses and the most important process parameters of TW-ECDM. The verification experiments have been performed to compare between predicted results and experimental results. Finally a 3-9-1 feed forward back propagation neural network has been used to predict the responses for different parametric combinations and those are compared with the actual results.

2. Experimental setup of TW-ECDM system

TW-ECDM system has been developed to carry out experimental investigation and optimal analysis of machining characteristics of TW-ECDM process. Fig. 1 shows the schematic diagram of the TW-ECDM setup. The TW-ECDM system consists of subsystems such as mechanical hardware unit, control limit for wire feeding and electrical power supply unit. The photographic view of the setup is shown in Fig. 2.



Legends: (1) Input spool, (2) Output spool with stepper motor, (3) Pulley for gravity feed mechanism, (4) Wire electrode (cathode), (5) Workpiece in vertical position, (6) Workpiece holding Perspex piece, (7) Auxiliary electrode (anode)

Fig. 1 Schematic view of the TW-ECDM setup

(a) **(b)**

Fig. 2 Photographic view of the TW-ECDM setup along with control units

Mechanical hardware unit consists of wire feeding unit, wire positioning unit, job holding unit and these units are fitted inside the main machining chamber. The wire feeding unit consists of input spool, output spool and a set of intermediate pulleys. The output spool is coupled with a motor and as the motor rotates it draws the wire out of the input spool through the intermediate pulleys. The wire feeding unit feeds the wire continuously as per the required feed rate. The wire positioning unit consists of three parts such as wire guide unit, wire guide positioning unit and effective wire length adjusting mechanism. It helps to keep the wire in touch with the work-piece. The job holding unit holds the job and controls the inter electrode gap. It also helps to facilitate the contact between the hydrogen bubbles evolved and the workpiece. The movement of the job holding unit can be controlled by means of gravity feed mechanism. Minimum gap between wire and auxiliary electrode is kept at 30 mm. For the purpose of experiment, the inter-electrode gap is fixed at 45 mm. The entire assembly is fitted in a machining chamber made up of Perspex which is kept in the lower platform of a two-storied wooden table. A hole is made at the bottom of the machining chamber and the lower platform of the wooden table, through which a lower Perspex piece with a central hole is attached. On the other side of the Perspex piece a plastic nozzle and gate valve assembly is attached. With this assembly a polyvinyl chloride made water spraying pipe is attached. The open end of the pipe is immersed in a big size plastic pail which collects the used electrolyte. Aqueous solution of KOH salt is used as electrolyte. The micro controller based stepper motor unit is a menu based operational system where both the speed and direction of rotation of stepper motor can be varied. The feed rate of wire can be set from 0.05-0.4 m/min. The rpm of the stepper motor can be varied from 1 to 80. The input voltage of the stepper motor is 12 V and the current to the stepper motor is 4 A. The traveling wire electrochemical discharge machining system demands for voltage of 5-150 V, current of 0-7 A and frequency of 50-2000 Hz depending on the rate of material removal and other machining criteria. Keeping in view of this need a pulsed dc power supply is developed. It provides the supply voltage from 0-100 V.

3. Planning for experimentation

Keeping in view the fact of properly controlling the machining performances, the objective of the present research has been to study the main influencing factors among pulse on time as a percentage of total time (A), frequency (B), applied voltage (C), concentration of electrolyte (D) and wire feed rate (E) affecting the responses like material removal rate (MRR) and radial overcut (ROC). Taguchi method based robust design principles [20] have been used for the purpose of employing a L_{25} (5^5) orthogonal array to study the effect of process parameters. Each factor is assigned 5 levels as listed in Table 1.

Considering the required properties like tensile strength, melting point of the material etc. brass wire of 0.25 mm diameter was chosen as cathode or tool. Hylam based fibre reinforced composites of 3 mm thickness were used as workpiece. Solution of KOH salt was used as electrolyte. The weight of the job before and after machining was measured and the difference was divided by machining time to get the material removal rate. For each experiment the time taken was 10 min. Olympus STM6 optical measuring microscope was used to measure the radial overcut. The weight of the workpiece before and after machining was measured by SARTORIUS GC103 digital balance. Each experiment is replicated 3 times to observe the readings of material removal rate and radial overcut.

Table 1 Factors with their levels

Control Factors	Levels				
	1	2	3	4	5
Pulse on Time – A, (%)	50	55	60	65	70
Frequency of power supply – B, (Hz)	55	65	75	85	95
Applied voltage – C, (V)	30	35	40	45	50
Electrolyte concentration – D, (%)	10	15	20	25	30
Wire feed rate – E, (mm/min)	50	125	175	225	300

4. Taguchi method based optimal parametric analysis

Taguchi method of robust design makes use of orthogonal arrays to determine the effect of various process parameters based on analysis of signal to noise (S/N) ratio (η). Mathematically it can be computed as

$$\eta = -10 \log (MSD) \quad (1)$$

where *MSD* is the mean square deviation and commonly known as quality loss function. Depending on experimental objective the quality loss function can be of three types: smaller the better, larger the better and nominal the best. The values of signal to noise ratio were calculated for material removal rate based on larger the better quality principle and for radial overcut based on smaller the better principle. The data summary in terms of S/N ratios are given in Table 2, and the results of analysis of variance for material removal rate and radial overcut are shown in Table 3 and Table 4, respectively.

Table 2 Data summary

Experiment No.	Factor Levels					S/N ratios (dB)	
	A	B	C	D	E	MRR	ROC
1	1	1	1	1	1	-11.7005	22.9748
2	1	2	2	2	2	-10.1728	17.2024
3	1	3	3	3	3	-9.1186	18.3443
4	1	4	4	4	4	-7.3306	19.0156
5	1	5	5	5	5	-7.3306	14.8945
6	2	1	2	3	4	-10.1728	19.4939
7	2	2	3	4	5	-9.1186	19.3315
8	2	3	4	5	1	-6.5580	10.2290
9	2	4	5	1	2	-7.7443	17.3933
10	2	5	1	2	3	-10.4576	23.6091
11	3	1	3	5	2	-7.5380	16.5948
12	3	2	4	1	3	-8.1737	18.7860
13	3	3	5	2	4	-7.1309	19.5762
14	3	4	1	3	5	-10.1728	18.5624
15	3	5	2	4	1	-7.1309	16.0269
16	4	1	4	2	5	-7.9588	17.8588
17	4	2	5	3	1	-5.8486	15.8097
18	4	3	1	4	2	-7.5350	18.8619
19	4	4	2	5	3	-7.1309	17.2656
20	4	5	3	1	4	-8.4043	17.7882
21	5	1	5	4	3	-4.5830	14.1993
22	5	2	1	5	4	-7.3306	19.4123
23	5	3	1	2	5	-8.4043	20.7242
24	5	4	3	2	1	-6.1961	15.1890
25	5	5	4	3	2	-5.1927	16.4205

Table 3 ANOVA for MRR

Factors	Degrees of freedom	Sum of squares	Mean square	F-Value	Contribution (%)
TON – A	4	25.2875	6.3219	13.1378	35.9804
Frequency – B	4	1.9085	0.4771	0.9915	2.7155
Applied voltage – C	4	27.5150	6.8788	14.2951	39.1498
Concentration – D	4	11.7040	2.9260	6.0806	16.6531
WFR – E	4	3.7470	0.9368	1.9468	5.3314
Error	4	0.1193	0.0298	-	0.1698
Pooled error	12	5.7748	0.4812	-	8.2170
Total	24	70.2813	2.9284	-	100.0000

Table 4 ANOVA for ROC

Factors	Degrees of freedom	Sum of squares	Mean square	F-Value	Contribution (%)
TON – A	4	4.8940	1.2235	0.2436	2.5509
Frequency – B	4	2.1930	0.5483	0.1902	1.1430
Applied voltage – C	4	61.8995	15.4749	3.0807	32.2634
Concentration – D	4	41.9480	10.4870	2.0877	21.8642
WFR – E	4	27.7315	6.9329	1.3802	14.4543
Error	4	53.1908	13.2977	---	27.7242
Pooled error	12	60.2778	5.0232	---	31.4181
Total	24	191.8568	7.9940	---	100.0000

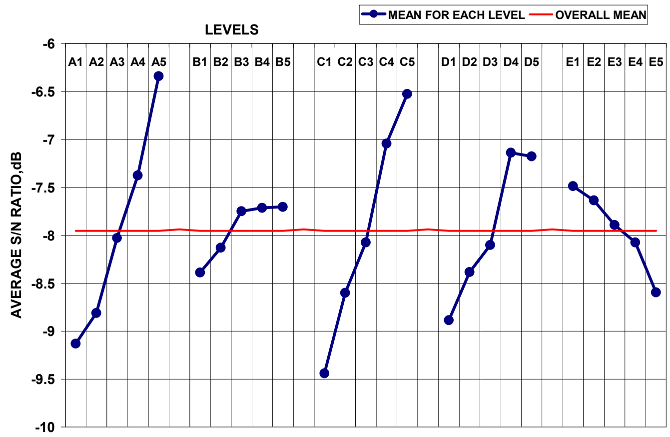


Fig. 3 S/N ratio plot for MRR

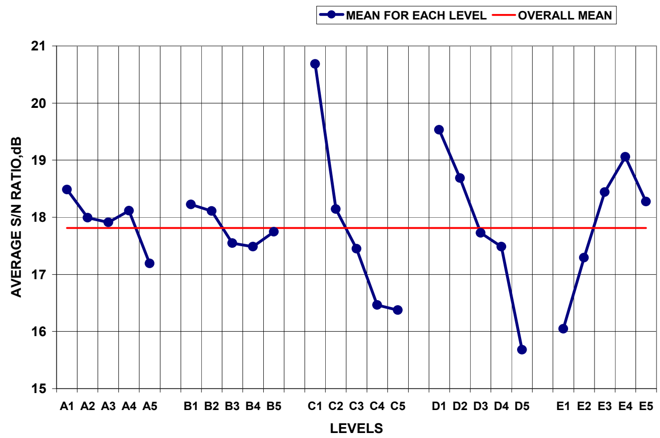


Fig. 4 S/N ratio plot for ROC

The corresponding factor effects at different levels for material removal rate and radial overcut in terms of S/N ratios are plotted in Fig. 3 and Fig. 4, respectively.

From S/N ratio plot it has been observed that for achieving maximum MRR the optimal parametric setting is $A_5B_5C_5D_4E_1$, i.e. pulse on time as 70 % of the total pulse duration, pulse frequency of 95 Hz, applied voltage of 50 V, electrolyte concentration of 25 % by weight and wire feed rate of 50 mm/min. For achieving minimum radial overcut the optimal parametric setting is $A_1B_1C_1D_1E_4$, i.e. pulse on time as 50 % of the total pulse duration, pulse frequency of 55 Hz, applied voltage of 30 V, electrolyte concentration of 10 % by weight and wire feed rate of 225 mm/min. Comparing the variances and degrees of contribution for each control factor it is realized that pulse on time, applied voltage and concentration of electrolyte are the most influencing factors for material removal rate and applied voltage, concentration of electrolyte and wire feed rate are most influencing factors for radial overcut. The percentage improvements in the optimum condition based on signal to noise ratio is listed in Table 5.

Table 5 Improvements based on S/N ratio

Responses	Starting condition (dB)	Predicted optimum condition (dB)	Percentage improvement (dB)
MRR	-11.5831	-3.4484	70.23
ROC	21.7309	24.7422	13.86

Table 6 Results of verification experiment

Responses	Optimal parametric settings					Values
	A	B	C	D	E	
MRR (mg/min)	70	95	50	25	50	0.620
ROC (mm)	50	55	30	10	225	0.065

It is observed that the percentage improvement of material removal rate is 70.23 % and of radial overcut is 13.86 %. The results of verification experiments are shown in Table 6.

5. Development of empirical models

The empirical models have been developed by non-linear multiple regression analysis on the basis of L_{25} (5^5) orthogonal array of robust design. In the analysis based on Taguchi method it was found that for material removal rate the most significant parameters are pulse on time as a percentage of total time, applied voltage and concentration of electrolyte. Empirical model for material removal rate is developed by considering the most significant process parameters. Empirical model for radial overcut is also developed by considering the most significant process parameters such as applied voltage, concentration of electrolyte and wire feed rate. The mathematical relationship between material removal rate and most significant process parameters is established as follows:

$$Y = 0.4170 + 0.0326X_1 + 0.0264X_2 + 0.0206X_3 + 0.0013X_1^2 - 0.0004X_2^2 - 0.0041X_3^2 \quad (2)$$

where $X_1 = \frac{(TON-60)}{5}$, $X_2 = \frac{(AV-40)}{5}$, $X_3 = \frac{(CONC-20)}{5}$ and Y = MRR (mg/min)

The mathematical relationship between radial overcut and the corresponding significant process parameters is as follows:

$$Y = 0.0651 + 0.0157X_1 + 0.0150X_2 - 0.0051X_3 - 0.0043X_1^2 + 0.0033X_2^2 + 0.0062X_3^2 \quad (3)$$

where $X_1 = \frac{(AV-40)}{5}$, $X_2 = \frac{(CONC-20)}{5}$, $X_3 = \frac{(WFR-175)}{25}$ and Y = ROC (mm)

As pulse on time increases more pulse energy is obtained per spark resulting in more heat generation during melting and hence material removal rate also increases. As applied voltage increases more pulse energy is obtained per spark and more heat is generated during melting and material removal rate also increases. More concentration of electrolyte means more conductivity of electrolyte and extent of chemical reaction also increases with the concentration of electrolyte. As degree of chemical reaction increases, more hydrogen vapour bubbles are formed resulting in more sparking and more heat generation in melting resulting in more material removal rate.

At low value of applied voltage, pulse energy per spark is less resulting in less heat generation during sparking. Rate of melting of material also decreases. As applied voltage increases energy per spark also increases resulting in more generation of heat during melting and radial overcut also increases. With the increase in concentration of electrolyte, radial overcut first increases and then decreases. At less value of concentration, vapour blanketing of wire is incomplete and irregular sparking causes more radial overcut. At moderate value of concentration extent of chemical reaction is more resulting in proper vapour blanketing of wire and more controlled and localized sparking resulting in minimum overcut. At higher values of concentration extent of chemical reaction is still greater than that of at a moderate electrolyte concentration and uneven and thicker blanketing of wire causes unstable and violent sparking and hence radial overcut is also maximum. As wire feed rate increases radial overcut first increases and then decreases. This is due to the reason that initially when chemical reaction occurs hydrogen bubbles are evolved and those bubbles form an insulating layer around the wire electrode. Then due to uniform sparking more materials are melted and hence radial overcut is also more. As wire feed rate increases, bubbles are swept away with the wire thus adversely affecting the sparking and hence less material is melt resulting in less radial overcut.

In the two equations derived above the resultant overall effect of all the above mentioned parameters are reflected.

Applied voltage was found to be most influential process parameter of TW-ECDM. Fig. 5 and Fig. 6 show the actual and estimated values of MRR and ROC for different levels of applied voltage.

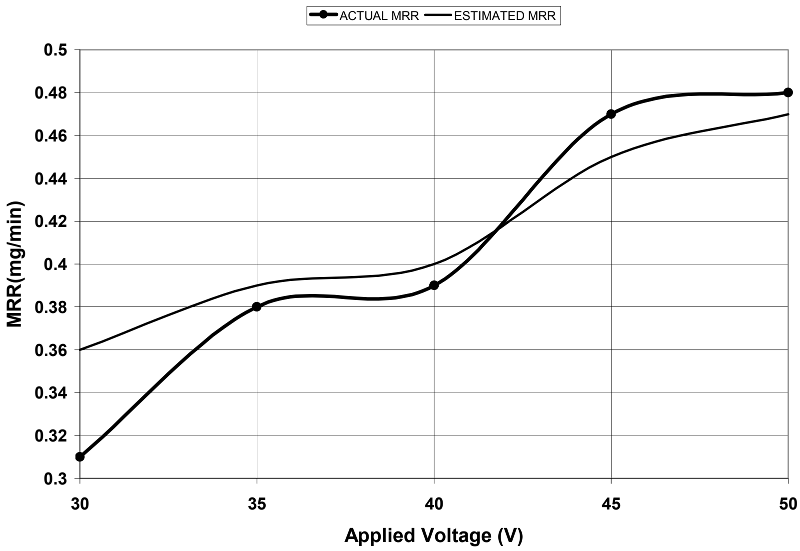


Fig. 5 Comparison of actual MRR and estimated MRR based on model

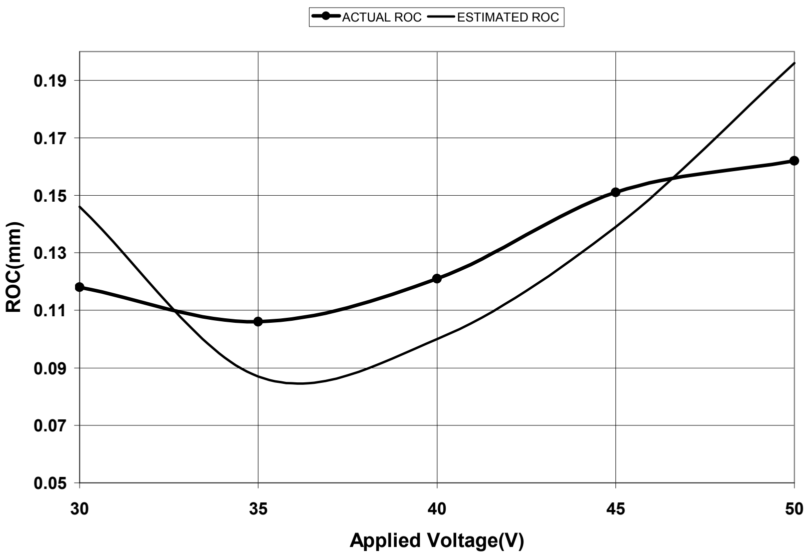


Fig. 6 Comparison of actual ROC and estimated ROC based on model

6. Artificial neural network

An artificial neural network (ANN) is a massively parallel distributed processor made up of signal processing units, which has a natural propensity for storing experiential knowledge and making it available for use. A neural network derives its computing power through, first, its massively parallel distributed structure and, second, its ability to learn and therefore generalize. Generalization means producing reasonable outputs from inputs not encountered during learning or training. These two information processing capabilities make it possible for neural networks to solve large scale problems that are currently intractable. In practice however neural network cannot provide solution by working individually. Rather they need to be integrated into a consistent system engineering approach. Specifically a complex problem of interest is decomposed into a number of relatively simple tasks and neural networks are assigned to a subset of the tasks that match their inherent capabilities. Different kinds of ANN architectures are single layer feed forward network, multilayer feed forward network, recurrent network etc. In multilayer feed forward network one or more hidden layers are present. The free parameters of a neural network are adapted through a process of stimulation by the environment in learning. Learning may be error correction learning, memory based learning, Hebbian learning, competitive learning, Boltzmann learning etc. according to methods. The model of environment in which the neural network operates is known as learning paradigm. Learning process may be supervised or unsupervised. Supervised learning algorithms employ an external reference signal and generate an error signal by comparing the reference with the obtained response. Based on the error signal the synaptic weights are modified. In back propagation neural network we have used back propagation supervised learning algorithm.

7. Prediction using ANN

In the feedforward backpropagation neural network model or perceptron there is an input layer, an output layer and one or more hidden layer. Each input layer has an input and an output. Like input layer each hidden layer and output layer has an input and an output. Weights are applied between outputs of input layer and inputs of hidden layer and and between output of hidden layer and inputs of output layer.

For input layer if linear transfer function is used, then

$$[O]_I = [I]_I \tag{4}$$

If hidden layer neurons are connected by synapses to input neurons then

$$[I]_H = [V][O]_I \tag{5}$$

where $[V]$ is weight matrix applied to output of input layer.

The unipolar sigmoidal transformation function is used for transformation of input of hidden layer to output of hidden layer. The unipolar sigmoidal transformation function is given by

$$O_{Hp} = \frac{1}{1 + e^{-\lambda I_{Hp}}} \tag{6}$$

where λ is sigmoidal.

For transformation of output of hidden layer to input of output layer is accomplished by

$$[I]_O = [W][O]_H \tag{7}$$

where [W] is weight matrix applied to output of hidden layer.

The transformation of input of output layer to output of output layer is given by the following unipolar sigmoidal function

$$O_{Op} = \frac{1}{1 + e^{-\lambda I_{Op}}} \tag{8}$$

After the output is obtained it is compared with the target value which is the experimental value and error is calculated as

$$E = \frac{1}{2}(T - O)^2 \tag{9}$$

where E is error, T is target value, and O is output value.

Based on the error and the learning algorithm, by trial and error methods the weights are changed again and again and the neural network is trained using the weights. A large number of iterations are performed until the values of error are sufficiently small and the required results are obtained.

Here a 3-9-1 feed forward back propagation network is used to analyze the performance separately for each output. The values of the machining parameters are taken as input and actual experimental values are treated as target values. The outputs of each experimental parametric setting are compared with the target values and errors are calculated. In this model of multilayer perceptron, linear activation function is used in input layer while unipolar sigmoidal function is used in both hidden layer and output layer. For material removal rate the value of sigmoidal gain is taken as 0.125 and for radial overcut the value of sigmoidal gain is taken as 0.130. Using programming through MATLAB the outputs and errors are generated. Table 7 shows the predictions for material removal rate while Table 8 shows the predictions for radial overcut.

Fig. 7 shows the relation between ANN values and experimental values for MRR and Fig. 8 shows relation between ANN values and experimental values for ROC. Combining the tables and the figures it can be concluded that this theoretical model can satisfactorily explain the complex experimental behaviour of the TW-ECDM process although there is still sufficient room for improvements. Fig. 9 shows variations in theoretical and experimental values in different experiments for MRR while Fig. 10 shows variations in theoretical and experimental values in different experiments for ROC. Fig. 11 shows microscopic view of one machined workpiece.

Table 7 Prediction for MRR using ANN

Experiment No.	Theoretical values	Actual values	Errors	Experiment No.	Theoretical values	Actual values	Errors
1	0.5665	0.2600	0.0470	14	0.5671	0.3100	0.0331
2	0.5669	0.3100	0.0330	15	0.5673	0.4400	0.0081
3	0.5671	0.3500	0.0236	16	0.5673	0.4000	0.0140
4	0.5672	0.4300	0.0094	17	0.5673	0.5100	0.0016
5	0.5673	0.4300	0.0094	18	0.5673	0.4200	0.0108
6	0.5671	0.3100	0.0331	19	0.5673	0.4400	0.0081
7	0.5672	0.3500	0.0236	20	0.5672	0.3800	0.0175
8	0.5673	0.4700	0.0047	21	0.5674	0.5900	0.0002
9	0.5671	0.4100	0.0123	22	0.5673	0.4300	0.0094
10	0.5669	0.3000	0.0356	23	0.5672	0.3800	0.0175
11	0.5673	0.4200	0.0109	24	0.5673	0.4900	0.0030
12	0.5671	0.3900	0.0157	25	0.5673	0.5500	0.0001
13	0.5672	0.4400	0.0081				

Table 8 Prediction for ROC using ANN

Experiment No.	Theoretical values	Actual values	Errors	Experiment No.	Theoretical values	Actual values	Errors
1	0.5929	0.071	0.1362	14	0.5935	0.118	0.1130
2	0.5934	0.138	0.1037	15	0.5933	0.158	0.0948
3	0.5935	0.121	0.1116	16	0.5935	0.128	0.1083
4	0.5935	0.112	0.1159	17	0.5934	0.162	0.0931
5	0.5935	0.180	0.0855	18	0.5934	0.114	0.1149
6	0.5935	0.106	0.1188	19	0.5935	0.137	0.1042
7	0.5935	0.108	0.1178	20	0.5935	0.129	0.1079
8	0.5934	0.308	0.0407	21	0.5935	0.195	0.0794
9	0.5934	0.135	0.1051	22	0.5935	0.107	0.1183
10	0.5934	0.066	0.1391	23	0.5935	0.092	0.1257
11	0.5935	0.148	0.0992	24	0.5933	0.174	0.0879
12	0.5935	0.115	0.1145	25	0.5934	0.151	0.0979
13	0.5935	0.105	0.1193				

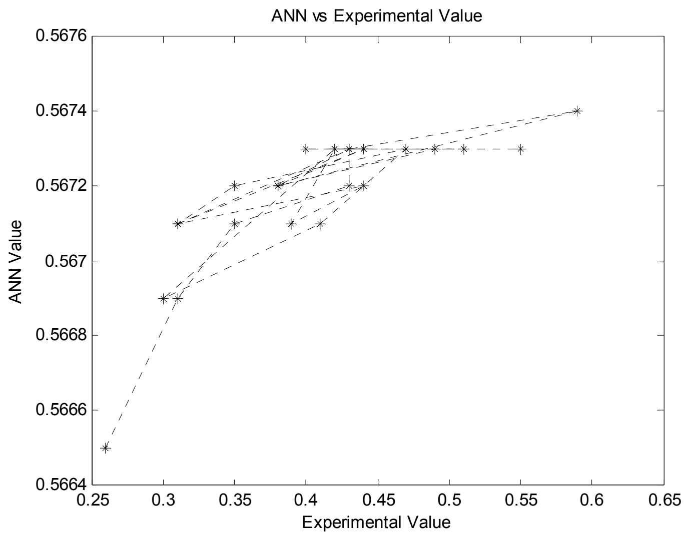


Fig. 7 Relation between ANN values and experimental values in MRR

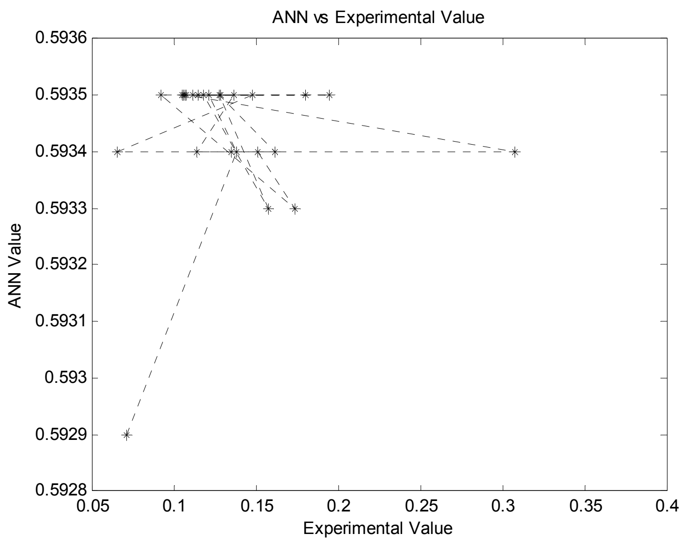


Fig. 8 Relation between ANN values and experimental values in ROC

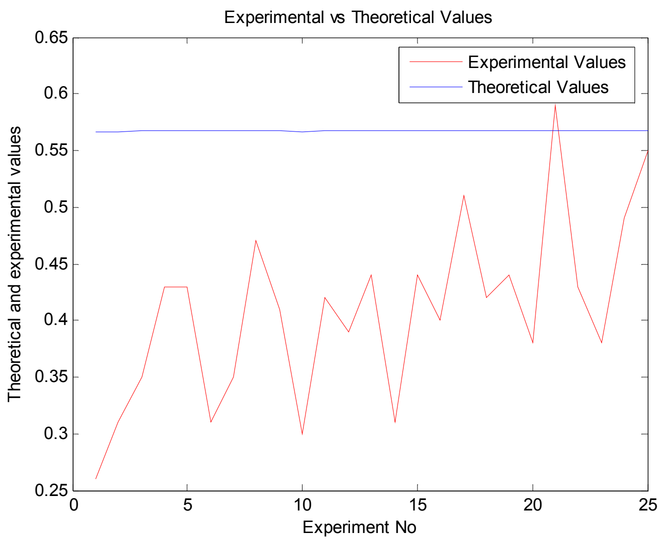


Fig. 9 Variation in MRR for different experiments

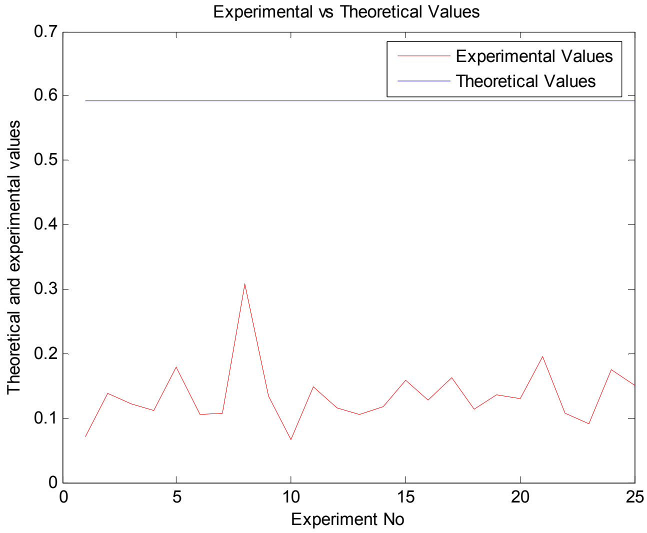


Fig. 10 Variation in ROC for different experiments

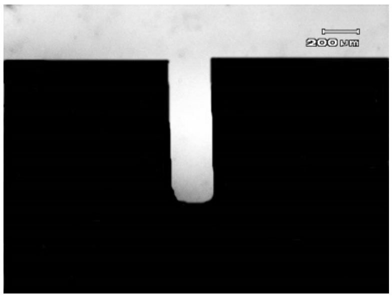


Fig. 11 Microscopic view of machined workpiece

8. Conclusion

The TW-ECDM system has ability to perform the machining operation such as cutting electrically non-conductive engineering materials like fibre reinforced composites. From the observed results and analysis on TW-ECDM process, it is clear that for maximum material removal rate (MRR) the parametric combination is pulse on time as 70 % of the total time, pulse frequency of 95 Hz, applied voltage of 50 V, electrolytic concentration of 25 % by weight and wire feed rate of 225 mm/min. For minimum radial overcut (ROC) the optimal parametric combination is obtained as pulse on time as 50 % of the total pulse time, frequency of 55 Hz, applied voltage of 30 V, electrolyte concentration of 10 % by weight and wire feed rate of 225 mm/min. From the analysis of variance pulse on time, applied voltage and concentration of electrolyte are found as more significant process parameters affecting material removal rate and applied voltage, concentration of electrolyte and wire feed rate as more significant process parameters affecting radial overcut. Earlier researches on ECDM and TW-ECSM focused mainly on developing experimental setup for machining ceramics and composites etc. and determining the nature of pulse, having an insight of material removal mechanism and mathematical modelling of the process to determine the response of the outputs against individual process parameters, but very few attempts have been made to classify the process parameters as dominant or recessive. Verification experiment has also been conducted to test the validation of experiments based on orthogonal array and it was proved that improvement in the machining output has occurred. The authors have earlier conducted research on TW-ECDM [19] but the scope of that research was only confined to single response and multi-response optimization though a hybrid method of Taguchi method and principal component analysis (PCA) and it also revealed the complex interaction between the process parameters. But that analysis did not predict the behaviour of the responses against process parameters and no mathematical relation have been developed. In the current research an analysis has been made enlightening the non-linear relationship of a single response like material removal rate and radial overcut. From the plot of material removal rate and radial overcut against applied voltage it was observed that in case of material removal rate the response increases with applied voltage and experimental values matches with estimated values to maximum extent between 35 V and 45 V where as both experimental and estimated values show similar trend of change between 35 V and 45 V. Thus it is observed that if material removal rate increases, radial overcut will also increase thus putting a restriction on arbitrarily increasing the material removal rate and reasonably good result can be obtained by machining with 35 V to 45 V, although maximum MRR is obtained for 50 V and minimum ROC is obtained for 30 V. Owing to the complexity arising out of using multiple parameters together, an effort has been made to fit a feed forward back propagation neural network model between the parameters and responses and after sufficient training of the network the results obtained showed similar results as in the case of multiple regression analysis. This effort has never been made in earlier researches. Prediction using ANN shows that as actual values increases the predicted values also increases and the errors indicate the degree of fitness of the ANN. Prediction by both multiple regression and ANN gives an idea that best value of machining with respect to MRR will occur at the higher end of the parameter ranges, which exactly matches with the earlier research by the authors. This necessitates the redesign of electrical and electronic circuits of the present setup. Also different kind of optimization of the responses can be attempted with the same set of parameters and with the same experimental setup. Different kind of electrolyte solution and different work materials can also be used with the present setup with modification. The present setup can also be modified for micromachining of ceramics and composites.

Acknowledgement

The authors acknowledge the financial support of UGC, New Delhi for Centre for Advanced Studies (CAS) phase III programme in the Production Engineering Department of Jadavpur University, Kolkata.

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